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Limited Human Factors Assessment of the QuadGard Limb Protection System: U.S. Marine Corps Systems Command Limb Protection Program Overview (QuadGard Phases IV and V Production Designs)

by Richard S. Bruno

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Army Research Laboratory

Aberdeen Proving Ground, MD 21005-5425

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14. ABSTRACT In response to blast-weapon threats and casualty trends in Operation Iraqi Freedom and Operation Enduring Freedom, the U.S. Naval Research Laboratory (NRL) was tasked to develop body armor that would protect Soldiers' extremities against blast fragments and small arms. NRL assembled a cooperative team to design and develop the QuadGard, which included the U.S. Army Research Laboratory (ARL), FS Technology, and Oklahoma State University. ARL's Human Research and Engineering Directorate assisted in evaluating the effects of the QuadGard on Soldier human factors. The Marine Corps Systems Command established three design requirements: (1) limb armor system compatibility between the standard outer tactical vest system, the personal armor system for ground troop helmet, and weapon interface, (2) detachable modular lower arm and leg armor segments, and (3) user mobility, flexibility, and comfort protection of vulnerable zones of the body. This report documents two limited human factors assessments and demonstrations of the QuadGard IV and V designs in which participants provided their opinions about their ability to perform generic tasks while wearing these systems. Limited results demonstrate that QuadGard did not interfere with the users' ability to negotiate an obstacle course, perform an exercise routine, shoot fire shoulder-fired weapons, and enter and exit military vehicles. The systems also allowed access for medics to perform field care. While wearing QuadGard, the participants rated their ability to perform exercise routines and generic tasks and rated system fit, form, and function from "acceptable" to "good." QuadGard V has since been patented and adopted by the U.S. Marines who use the system in Iraq and Afghanistan.					
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1. Introduction

In response to blast-weapon threats and casualty trends in Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF), the U.S. Secretary of the Navy, Gordon England, tasked the U.S. Naval Research Laboratory (NRL) to develop body armor that would protect Marine extremities against blast fragments and small arms.

As the program lead, NRL assembled a cooperative team to design and develop the QuadGard. This team included the U.S. Army Research Laboratory (ARL), FS Technology, and Oklahoma State University, with funding from the Office of U.S. Naval Research and U.S. Marine Corps Systems Command (MARCORSYSCOM).

The QuadGard design was produced to provide ballistic protection for arms and legs in response to blast-weapon threats and combat casualty trends in OIF and OEF. This effort produced small numbers of prototypes in design phases I and II and culminated in the phase III design between April and December 2004. January through August 2005 saw the development and initial fielding of the phase IV QuadGard system in Iraq and Afghanistan with the U.S. Marine Corps. October 2005–April 2006 marked the progression of the QuadGard system into the phase IV modular design with its subsequent fielding.

These QuadGard designs would give mounted and dismounted Marines an option for protection in operational situations where blast weapons and improvised explosive devices (IEDs) might be encountered. In operational terms, the QuadGard ballistic protection can increase the nonlethal and safe operating area around an IED by reducing the minimum standoff distances from the Marine to the device. An associated reduction in injury severity can mean quicker return to duty, reduced need for intensive medical treatment and rehabilitation, or the difference between injuries producing and not producing amputation disabilities.

ARL's mission was to assist in calculating the ergonomics associated with ballistic protection. MARCORSYSCOM established three design requirements: (1) system compatibility with the standard outer tactical vest (OTV) system, the personal armor system for ground troop helmet, and weapon interface, (2) detachable modular lower sleeve and trouser armor segments, and (3) the ability not to hinder the user's mobility, flexibility, and comfort while protecting vulnerable zones of the body.

ARL's Human Research and Engineering Directorate (HRED) provided human factors design guidance so the Marines could maximize user acceptance of the QuadGard limb protection system. The design philosophy was to optimize limb protection while minimizing the impact to the user's mobility.

The design was based on areas designated for protection through analyses of injury patterns by the U.S. naval medical authorities and anatomical and human factors considerations to ensure compatibility, mobility, and user acceptance.

QuadGard II was based on a “chaps”-style pants or trouser form with light duty suspenders, waist belt, and articulated sleeve segments, which were anchored to the current OTV. The QuadGard configurations evolved from a series of human factors evaluations and demonstrations. This report documents the successful demonstration of an 11-lb QuadGard IV and a 14.5-lb QuadGard V modular ballistic protection system with level IIA protection that supplements the OTV for less than \$1500 per set.

The QuadGard IV evaluation was completed, and human factors design guidance and recommendations were forwarded to NRL. In an evolutionary mode, QuadGard V incorporated a feature that detaches the lower portion of the sleeve and trouser. The initial QuadGard V evaluation was canceled by ARL because of safety issues surrounding the faulty disengagement of the system designed to secure the lower portion of the sleeve and trouser. ARL recommended a means to resecure the system. After the correction was incorporated, a QuadGard V evaluation was conducted in the same manner as QuadGard IV. ARL conducted limited demonstrations to assess crew station compatibility and exit/entry, medic access, and supported movement of the Marine/Soldier. The U.S. Army Rapid Equipping Force (REF), with ARL assistance, conducted operational evaluations of the QuadGard and two other prototype limb protective systems with the Army, Marines, and Air Force. This report summarizes the steps taken by ARL that supported evaluating and refining QuadGard phases IV and V. Appendix A lists evolutionary design modifications starting from the basic QuadGard phase.

2. Objective

The objective of this limited assessment was to provide human factors design guidance to NRL, which would further the QuadGard development, and to evaluate the QuadGard limb protective system, phases IV and V.

3. Method

3.1 The QuadGard System

The QuadGard limb protective system consists of a ballistic protective trouser and two sleeves that attach to the standard OTV. The trouser has an integral waist belt and suspender. The wide elastic yoke suspender is the second method to support the trouser. The suspender was sewn at the high back of the trouser and anchored below the top edge of the waist in the front by a

Fastex* quick-release buckle. An access closure was situated at the user's hip area. The trouser length extends to just above the user's boot. Each leg of the trouser has a full-length zipper on the outside to permit boot passage. The trouser was designed so that its weight would be supported by the waist belt and the suspender. The trouser should react to the wearer's body movement.

The sleeves were three integrated sections that cover three-fourths of the user's arm (or approximately to the user's wrist). The two sleeves attach with Velcro[†] to the OTV epaulette and an integral loop and with a Fastex quick-release buckle to a rear sleeve-to-sleeve anchorage strap. Figure 1 shows a Soldier wearing the QuadGard IV limb-protective system. QuadGard IV weighs ~10 lb (the trouser weighs 7 lb, and each sleeve weighs 1.5 lb). Figure 2 shows QuadGard V (the entire system and with the lower portions detached). QuadGard V weighs ~13.4 lb (the trouser weighs ~9.4 lb, and each sleeve weighs 2 lb). The detachable lower sleeve and trouser portions are design features specific to the QuadGard V. The lower portion of the sleeve (0.88 lb) detaches just above the elbow area, and the lower portion of the trouser (1.1 lb) detaches just above the knee.



Figure 1. Front and back views of the QuadGard IV.

*Fastex is a registered trademark of Nexus N. A.

[†]Velcro is a registered trademark of Velcro Industries B.V.



Figure 2. Front views of the QuadGard V (shown on the left is QuadGard V without the lower portion of the sleeve and trouser).

There are five differences between QuadGard IV and V. QuadGard V has detachable lower portions of the sleeves and trouser legs. Also, the sleeves and legs of QuadGard V were enlarged to permit better air flow and arm and leg movement. On QuadGard V, the sleeve attachment device was modified with a narrower pass-through strap to make attaching the arms to the OTV easier. Also, the suspender on the QuadGard V was made fully detachable and wider, and the hip/waist adjustment was improved. The zipper on the outside of the leg on the QuadGard V was modified by adding an internal protective flap, and pull tabs were added to the zipper pull.

3.2 Variables

3.2.1 Independent Variables

Evaluation 1 compared QuadGard IV to the OTV, and evaluation 2 compared QuadGard V with full arms and legs (QGVF) to QuadGard V with half arms and legs (QGVH). The independent variables were the QuadGard configurations.

3.2.2 Dependent Variables

The dependent variables were the participants' subjective responses to the conditions.

3.2.3 Experimental Matrix

The sequence of exposure was QuadGard IV, QuadGard V Full and QuadGard V Half. Questionnaires were administered after each condition.

3.3 Participants

In total (across both studies), 19 enlisted military participated in the QuadGard evaluations at the ARL HRED mobility and portability (MP) obstacle course and weapons firing at M-range. The participants for the QuadGard IV vs. OTV evaluation were four male Marines from the Marine detachment. The participants for the QuadGard VF vs. QuadGard VH were seven female and eight male Army Soldiers from the 16th Ordnance Battalion (both entities are located at Aberdeen Proving Ground, MD). Because of the QuadGard sizes available for this evaluation, participants were chosen to be a minimum 5 ft 5 in (5th percentile male, 65th percentile female) or taller. All participants were in excellent physical shape and had previously passed the Marine/Army physical fitness test.

3.4 Procedures

The procedures for both evaluations were essentially the same. All participants were sized and fitted with the QuadGard, OTV (without plates), and an infantry helmet. The participants proceeded through a nonobstacle course exercise routine designed to assess the effect of QuadGard on range of motion and to identify fit or compatibility problems between the QuadGard, the OTV, and helmet. Range of motion was not objectively quantified in these evaluations. The nonobstacle course exercise routine is as follows:

1. Arms extended horizontally to the sides.
2. Arms crossed horizontally to the front.
3. Arms swung horizontally to the rear.
4. Arms raised vertically, then palms touch.
5. Arms extended horizontally, hips fixed, flex thorax forward.
6. Arms extended horizontally, hips fixed, flex thorax to the rear.
7. Arms extended horizontally, hips fixed, rotate thorax.
8. Feet apart, bend right knee and touch floor/ground.
9. Feet apart, bend left knee and touch floor/ground.
10. Feet apart, bend both knees and assume a squat position.
11. Feet apart, standing upright, grenade in hand, extend right arm backward then forward to throw an inert grenade.
12. Feet apart, bend right knee and touch the floor/ground to squat, grenade in hand, extend right arm backward then forward to throw an inert grenade.
13. Assume the prone firing position. Using the right hand, grasp an inert grenade and throw the grenade forward at target.

14. Assume the prone firing position and shoulder weapon with right arm.
15. Assume kneeling firing position on right knee, then stand upright quickly.
16. Assume kneeling firing position on left knee, then stand upright quickly.
17. Climb ladder (at least four steps) upward, then downward.
18. Climb stairs (at least four steps) upward, then downward.
19. Low crawl on elbows and knees for a short distance (30 ft).
20. Walk quickly for a short distance (50 ft).
21. Run quickly for a short distance (50 ft).

3.5 MP Obstacle Course Negotiation

After completing the nonobstacle course exercise routine, the participants negotiated the ARL HRED MP obstacle course. This course consisted of a series of obstacles spread over a 500-m serpentine track (figure 3). The obstacles on this course have been chosen to represent the kinds of dynamic maneuvers that a Marine/Soldier would be expected to perform in a combat assault: running, jumping, climbing, balancing, and crawling. For the first evaluation (OTV vs. QuadGard IV), time to complete the obstacle course was collected. This data was not collected for the second evaluation (QuadGard VH vs. QuadGard VF).

3.6 Live Firing at M-Range

While wearing the QuadGard, OTV, and helmet, the participants fired the M4 rifle from the prone and standing postures. Pop-up targets ranged from 50 to 300 m and went down when hit. Presentation order and sequence of targets were randomized.

After the participants completed nonobstacle course exercises, obstacle course runs, and live firing in a QuadGard condition, questionnaires were administered to gather opinions regarding system fit, features, and effects on their performance (appendix B).



Figure 3. The 500-m MP obstacle course.

4. Results

During the debriefing session, the participants reported no fitting problems associated with the QuadGard systems, and that their ability to complete the exercise routine was not hindered. Typically, the participants reported a good to acceptable response regarding their ability to perform the assigned tasks (sit, walk, run, climb a ladder and stair, squat, kneel, shoulder a weapon, and throw a grenade; refer to figures C-1–C8). The participants reported to the investigator that the QuadGard systems acted as a protective layer that kept the rough edges of the obstacle course away from their bodies.

Results of questionnaire data regarding system fit, features, and effects on performance were summarized and illustrated in appendix C. The graphs in appendix C illustrate the comparative data for QuadGard IV and V. QuadGard V data were collected and illustrated as VF (full QuadGard V ensemble) or VH (half QuadGard V ensemble). The only negative comment received was about the orientation of the adjustable Velcro pull tabs on the side of the trouser. The tabs should be reoriented on the next phase of QuadGard (IV and V). In general, the fasteners and closures on the QuadGard systems were reported to be acceptable.

Overall, a review of the data shows the QuadGard sleeve portion fit was acceptable. Participants reported that the QuadGard systems' sleeves were easy to put on and take off and easy to attach to and detach from the OTV (figure C-1). QuadGard V was rated in one of the evaluations as

being between good to excellent, and the QuadGard IV system was generally rated acceptable by participants in the other evaluation. There was also a noticeable difference in the ratings between the two QuadGard V systems. The QuadGard V half sleeve was rated between good and excellent for comfort, while the QuadGard V full sleeve was rated as acceptable.

For the questionnaires that asked participants of both studies to rate the trousers, the trouser fit was described as roomy; the comfortable suspenders and moderate bulk allowed for easy removal (figures C-3 and C-4).

For the questionnaires regarding moving with the limb protection system (figure C-5), the ability to move or maneuver while wearing any of the QuadGard systems was generally scored as acceptable or higher for compatibility ratings. Body movement was rated as neutral. There was a large difference in ratings for how much the QuadGard systems bunched up. One group of subjects reported that QuadGard IV bunched up moderately, and the other group reported that the QuadGard V system stayed flat.

The participants rated the fasteners and closures for each QuadGard system. In general, the adjustment, ruggedness, effectiveness, location, ease of adjusting, and how they stayed adjusted were rated by one group as acceptable for the QuadGard IV system and good for the QuadGard V system by the other group. The ability to grip the fasteners and closures was rated as acceptable for all QuadGard systems.

Participants also rated performance of various tasks in the QuadGard systems. Overall, perceived task performance was rated above acceptable with most tasks rated as good (figures C-7–C-9). The task rated the lowest by the test participants was “run a short distance,” which generally had an acceptable rating for all QuadGard systems.

The participants were debriefed regarding QuadGard compatibility and effect on their ability to fire while wearing the QuadGard, OTV, and a helmet. In general, the participants reported that the QuadGard systems provided a cushion that surrounded the shooter. The participants’ elbows were cushioned while in the prone and standing supported firing positions (figure 4). The QuadGard trouser was viewed as a good buffer, which protected knees and cushioned legs while on rough surfaces. Statistical inference on shooting performance could not be made since insufficient firing comparison data were collected.

For the obstacle course data, test participants in the first study took an average time of 6 min 6 s to complete the course while wearing the OTV and helmet. When participants wore the QuadGard IV with OTV and helmet, the average course time was 8 min and 54 s. The QuadGard IV degraded their timed performance by 32%, compared to the no-QuadGard time data. Obstacle course completion data were not collected for the QGVH vs. QGVF evaluation. Based on previous assessments, the slower course completion times may be expected when wearing the QuadGard system because of the additional weight; these effects may be compounded because of the additional weight of the system being located on the extremities.



Figure 4. Participant firing an M4 rifle while wearing QGVH (left) with and QGVF (right).

4.1 Demonstrations or Limited Assessments of the QuadGard

The following demonstrations or limited assessments were conducted to assess QuadGard V compatibility and function of system features:

- Limited armored-vehicle crew station compatibility and entry/exit
- QuadGard V detachable lower portions
- Medic's access to individual wearing QuadGard
- QuadGard support strap/handle
- REF assessments

4.2 Limited Armored-Vehicle Crew Station Compatibility and Entry/Exit Evaluation

A cursory assessment was conducted of QuadGard compatibility and the wearer's mobility and ability to move, reach/activate controls, and then exit Marine and Army "up-armored" and armored vehicles. Two male Army Soldiers (50th and 70th percentiles in stature) participated in a very limited QuadGard IV system compatibility and exit/entry assessment. They wore the QuadGard, OTV, and infantry helmet, and carried an inert rifle. The participants entered the driver and passenger crew stations and assessed their mobility and ability to move, reach/activate controls, and exit the compartment (see figure 5). The following vehicles (available at Aberdeen Proving Ground, MD), were accessed while wearing the QuadGard, OTV, and infantry helmet:

- M967 fuel tanker
- M969 fuel tanker
- M1062 fuel tanker
- M978A2R heavy expanded mobility tactical truck (HEMTT)

- M985A2 HEMTT
- M1070 heavy equipment transporter
- M1075 palletized load system
- 1151P1 high-mobility multipurpose wheeled vehicle (HMMWV)
- M998 HMMWV
- M1126 infantry carrier vehicle (Stryker)



Figure 5. Participant wearing QuadGard IV while exiting a Stryker vehicle from the rear compartment (left) and participant wearing QuadGard IV while assessing the driver's crew station (right).

Results of this limited assessment found the QuadGard to be compatible with driver and passenger crew stations. Participants reported that their mobility and access to the controls were not impeded. Also, entering and exiting the vehicles were reported and viewed to be easily accomplished. Only one compatibility problem was encountered: while participants exited the HEMTT's driver compartment, the flap of armor that covered the rear of the lower leg and was secured with Velcro would snag on the HEMTT's driver's seat air-ride-seat control knob. The Velcro disengaged, as designed, to allow the wearer unimpeded leg movement. The control knob is used to adjust the driver's seat height and, in updated HEMTTs, may be relocated to the side of the driver's seat. The participants noted no other problems. While in the cupola,

participants noted that the arms segments of the QuadGard would protect and prevent hot expended shell casings from contacting the firer's arms.

Note that this assessment was performed with medium size equipment and personnel who were not extremely tall or bulky. Marines/Soldiers who are tall or wearing bulky equipment will likely experience difficulty maneuvering in and around vehicle crew stations and cupolas. The present crew stations, driver compartments, entry/exit hatches, and cupolas are not necessarily designed to accommodate large Marines/Soldiers with field gear or bulky body armor.

4.3 Demonstrating QuadGard V Detachable Lower Portions (Sleeves and Trouser)

The lower portions of the sleeves and trouser on QuadGard V can be detached by disengaging a dot snap anchorage and unzipping the segments (shown in figure 6). Four of the participants were timed at detaching and removing the lower portions of the QuadGard. The average time to remove both lower leg portions was 42 s. The average time to remove both lower sleeve portions was 15 s. All lower sleeves and trouser portions were removed from the QuadGard in an average of 57 s.



Figure 6. Participant detaching and removing the right-lower trouser portion of the QuadGard V (left) and participant detaching and removing the left arm portion of the QuadGard V (right).

4.4 Demonstrating a Medic's Access to Individual Wearing QuadGard

Gaining access to a simulated wounded Marine/Soldier wearing QuadGard IV or V was easily accomplished with a minimal amount of disruption or movement. QuadGard IV and V were designed with hook and pile, dot snaps, and large zippers on the outside of the trouser. After the medic attended the wound, the QuadGard was reemployed and provided continued protection from the engagement site to a medical facility.



Figure 7. Image showing how a medic accesses a wounded Marine/Soldier with minimal movement.

4.5 Demonstrating the QuadGard Support Strap/Handle

The QuadGard has an integral strap or handle on the rear top edge of the trouser, which was designed to support the wounded Marine/Soldier. All participants were able to locate and grasp, as well as maneuver, a fellow Marine/Soldier with the QuadGard rear waist strap and the rear utility on the OTV. Figure 8 shows the support strap/handle being used in conjunction with the rear utility strap on the OTV.



Figure 8. A fellow Marine/Soldier lifting a Marine/Soldier off the ground by the QuadGard rear waist strap/handle and the rear utility strap on the OTV.

5. Discussion and Conclusion

The QuadGard systems were designed to be worn close to the body. After the participants completed the exercise routine, they reported that there was no negative impact caused by the QuadGard systems that affected/limited normal range of movement.

The QuadGard V system was rated more favorably than the QuadGard IV system in several areas. Participants perceived the sleeves of the QuadGard V system as easier to put on, take off, and attach and detach from the OTV. This difference was most likely due to design changes made to the QuadGard V system. The sleeves were made slightly larger in diameter to allow more airflow and less constriction. This widening also made it easier for the participants to put on and take off the sleeves. The strap used to attach the sleeve to the OTV was made slightly narrower on the QuadGard V system, which allowed participants to more easily attach the sleeves to the OTV; this ease was reflected in their ratings for this task.

There was also a difference in perceived ruggedness, effectiveness, location, ease of adjustment, and staying adjusted between the QuadGard IV and V conditions. Ratings for the QuadGard IV were generally lower than the ratings for the QuadGard V. These rating differences on the fasteners and closures were probably due to several design modifications that were made to the QuadGard V system. The suspenders were widened and made so that they could be completely

detached. The hip/waist adjustment was improved, and a pull tab was added to the zipper pulls on the outside of the leg. These design modifications resulted in generally higher ratings of the fasteners and closures of the QuadGard V system.

Due to the ability of QuadGard V to have the lower sleeves and lower legs removed, the QuadGard V system was evaluated in both its full and half conditions. One notable rating difference between the QuadGard V full and half conditions was that participants rated the half sleeve as much more comfortable than the full sleeve.

Participants did not have any negative comments about the QuadGard system for shooting shoulder-fired weapons. During a debriefing session, participants also stated that it protected the body from the rough edges encountered both while firing and when maneuvering through the obstacle course.

In general, the ability to move or maneuver while wearing the QuadGard systems was rated acceptable or higher. Participants completed the obstacle course 32% faster when wearing the QuadGard IV system compared to helmet and OTV. (Obstacle course completion times were not collected for the QuadGard VH vs. QuadGard VF evaluation.) The trousers of the QuadGard systems were viewed as somewhat bulky for long-range walking or maneuvering through brush. The lowest-rated task for the exercise assessment was running a short distance, and data on ability to run a long distance was not collected. These findings show that being able to maneuver quickly is affected by the QuadGard system. The added weight and bulk of the system (and the related performance decrements and increased heat stress) must be balanced with the benefits of providing extremity protection.

The QuadGard was designed to protect the extremities of Soldiers/Marines in various missions:

- Vehicle occupants/convoy crews
- Sentry and checkpoint duty
- Security and support operations
- Roadside patrols
- Explosive ordnance disposal reconnaissance units
- Forward deployed medical personnel
- First elements of breaching parties

The performance decrements noted with QuadGard may be mitigated in some missions due to the nature of the mission. For instance, the system may offer a greater advantage to vehicle occupants that are not required to carry the additional weight than it may offer a dismounted Soldier. Appendix D shows the participants wearing the QuadGard V during the nonobstacle course exercises, mobility/portability obstacle course, and live firing.

Appendix A. Recommended Design Modifications of QuadGard IV and V

The following specific QuadGard configuration design guidance and recommendations were made after the user feedback assessments and investigator review. Recommendations for the configuration of the QuadGard IV and V are (1) to reduce or eliminate the restrictions on the body in motion, (2) to improve air movement between the wearer and the armor, and (3) to improve the function of the configuration.

Shoulder pad

- Reshape to eliminate outer tactical vest (OTV) interference.

Three-point OTV attachment system

- Rear strap – modified to pass under OTV small-arms protective insert pocket flap.
- Center strap – use Velcro* instead of dot snap attachment.
- Add three positions on the front strap for sleeve length adjustment.

Upper sleeve

- Add protection to minimize frontal exposure.
- Replace Cordura[†] with ripstop inner liner to facilitate donning/doffing.
- Modify sleeve configuration with detachable lower sleeve segment just above the elbow. Use heavy zipper and dot snaps anchorage – QuadGard V.

Lower sleeve

- Increase the circumference by 1 in to ease donning/doffing and movement.
- Add a ventilation material flap along the lower edge and secure it with a Velcro strap.
- Replace Cordura with ripstop inner liner to facilitate donning/doffing.

Trouser waist

- Position a small Fastex[‡] closure on a belt on each hip area to improve fit and allow access to pockets.

*Velcro is a registered trademark of Velcro Industries B. V.

[†]Cordura is a registered trademark of AHH.Biz

[‡]Fastex is a registered trademark of Nexus N.A.

- Add a flap fold-back feature with Velcro to maintain the open/accessible position to pockets.
- Reverse the side waist adjustments so that Fastex buckle is oriented toward the front.
- Replace present belt buckle with a large Fastex buckle on the waist belt.
- Add a ventilation flap with Fastex quick release buckle along the outer edge of the trouser.
- Modify the suspender attachments with a Fastex quick release buckle.
- Replace Cordura with a ripstop inner liner to ease donning and doffing.
- Adjust the side waist belt pull tap so it can be tightened by pulling downward at a 30° angle.

Upper trouser

- Increase the circumference by 1 in to ease donning/doffing and movement.
- Modify trouser configuration with a detachable lower trouser segment at knee. Use heavy zipper and dot snaps anchorage – QuadGard V.

Knee area of trouser

- Attach material to the side openings of the back of knee armor rear flap to eliminate the brush catcher or tripping hazard.
- Trim both sides of the knee pads by 3/4 in to reduce trouser “stove pipe” appearance.
- Increase the circumference by 1 in to ease donning/doffing and movement.
- Increase the flexibility of knee design.
- Add an integral knee pad for comfort.

Lower trouser

- Add a ventilation material flap along the outer edge and secure it with a Velcro strap.
- Add Velcro tie-downs over the zipper.
- Replace the Cordura with a ripstop inner liner to ease donning/doffing.
- Increase the circumference by 1 in to ease donning/doffing and movement.

Trouser (general)

- Attach 3/4-in pull tabs to all zippers to improve zipper grasp.
- Modify trouser configuration with detachable lower trouser section just above the knee. Use heavy zipper and dot snaps anchorage.
- Add a Fastex quick release to front and rear segments of suspender.

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Appendix B. QuadGuard Limb Protection System Questionnaire

This appendix appears in its original form, without editorial change.

“QuadGuard” Limb Protection System Questionnaire

After wearing the limb protection system, mark your rating with an “X” in the appropriate box describing your perception of the limb protective system. Mark each line from Excellent = 5, Good = 4, Acceptable = 3, Poor = 2, Unsatisfactory = 1.

System (arm) Fit & Features

	Excellent	Good	Acceptable	Poor	Unsatisfactory
Put on	5	4	3	2	1
Attach	5	4	3	2	1
Detach	5	4	3	2	1
Take off	5	4	3	2	1
Trim	5	4	3	2	1
Elbow Location	5	4	3	2	1
Arm Room	5	4	3	2	1
System Comfort	5	4	3	2	1

System (Leg) Fit & Features

	Excellent	Good	Acceptable	Poor	Unsatisfactory
Put on Pants	5	4	3	2	1
Put on Suspenders	5	4	3	2	1
Take Off Pants	5	4	3	2	1
Trim	5	4	3	2	1
Good Knee Location	5	4	3	2	1
Roomy Legs	5	4	3	2	1
Comfort of System	5	4	3	2	1
Comfort of Suspenders	5	4	3	2	1

While moving with the limb protection system, describe your perception of the system by selecting one rating (Excellent, Moderately, Neutral) per pair of bipolar descriptive adjectives.

	Extremely	Moderately	Neutral	Moderately	Extremely	
Hot						Cool
Trim						Bulky
Bunches Up						Stays Flat
Allows Movement						Restricts Movement
Binds Body						Moves Freely
Uncomfortable						Comfortable
Compatible						Incompatible

After wearing the limb protection system, mark your rating with an “X” in the appropriate box describing your perception of the limb protective system. Mark each line from Excellent = 5, Good = 4, Acceptable = 3, Poor = 2, Unsatisfactory = 1.

Fasteners & Closures of the Limb Protective System

	Excellent	Good	Acceptable	Poor	Unsatisfactory
Adequate Adjustment	5	4	3	2	1
Rugged	5	4	3	2	1
Effective	5	4	3	2	1
Well Located	5	4	3	2	1
Easy to Grip	5	4	3	2	1
Easy to Adjust	5	4	3	2	1
Holds Adjustment	5	4	3	2	1

Limb Protective System Effect on Performance

	Excellent	Good	Acceptable	Poor	Unsatisfactory
Stand at Rest	5	4	3	2	1
Sat on Bench	5	4	3	2	1
Ran a Short Distance	5	4	3	2	1
Reach Overhead	5	4	3	2	1
Climb Stairs	5	4	3	2	1
Climb a Ladder	5	4	3	2	1

Limb Protective System Effect on Performance

	Excellent	Good	Acceptable	Poor	Unsatisfactory
Low Crawl	5	4	3	2	1
High Crawl	5	4	3	2	1
Get into Prone Firing Position	5	4	3	2	1
Get into Standing Firing Position	5	4	3	2	1
Lean or Bend Forward	5	4	3	2	1
Climb a Ladder	5	4	3	2	1

Limb Protective System Effect on Performance

	Excellent	Good	Acceptable	Poor	Unsatisfactory
Squat (both legs)	5	4	3	2	1
Kneel on Right Knee	5	4	3	2	1
Kneel on Left Knee	5	4	3	2	1
Kneel on Both Knees	5	4	3	2	1
Walk a Short Distance Forward	5	4	3	2	1
Walk a Short Distance Backward	5	4	3	2	1
Walk a Long Distance Forward	5	4	3	2	1

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Appendix C. Questionnaire Responses – Performance Assessments

In the following figures, IV = QuadGard IV, VF = QuadGard V full ensemble, and VH = QuadGard half ensemble (lower sleeve and trouser portions detached).

The numerical rating shown in the figures uses the following scale: 5 = excellent, 4 = good, 3 = acceptable, 2 = poor, and 1 = unsatisfactory. Data for condition IV are separated on the chart because the collection was part of a different study than the collection for VF and VH.

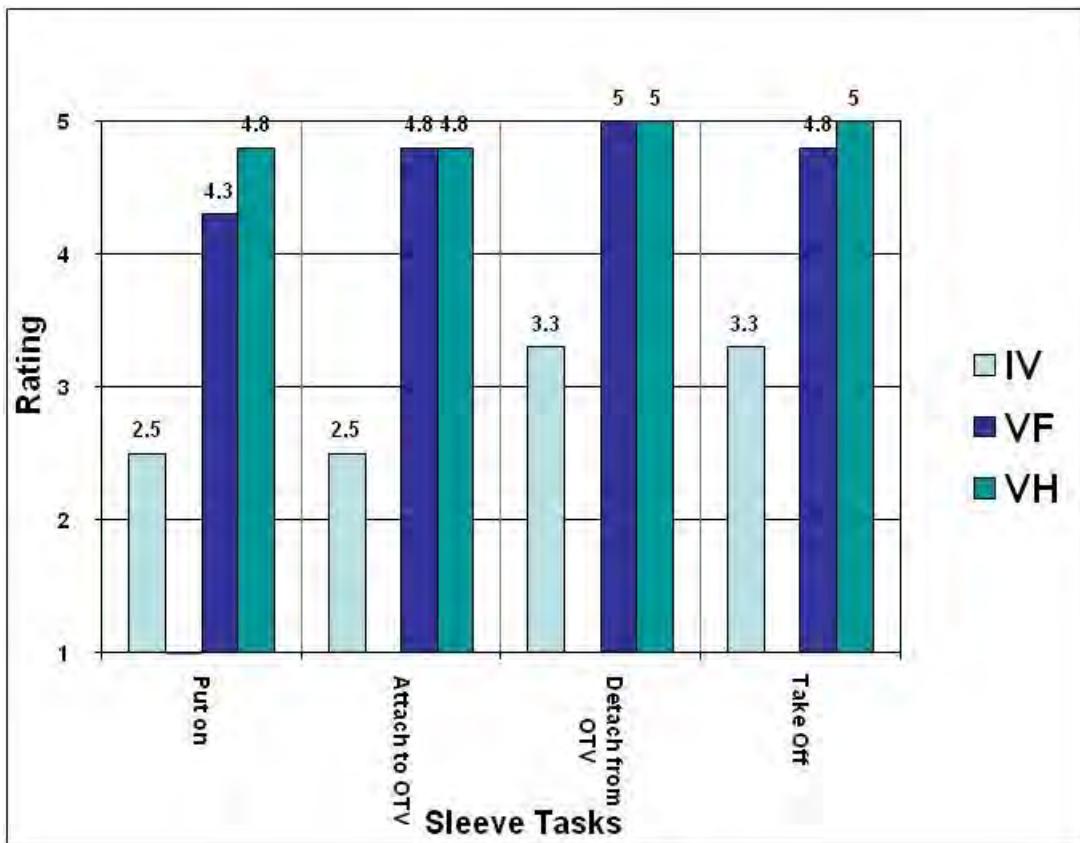


Figure C-1. Participant ratings related to tasks and sleeve system.

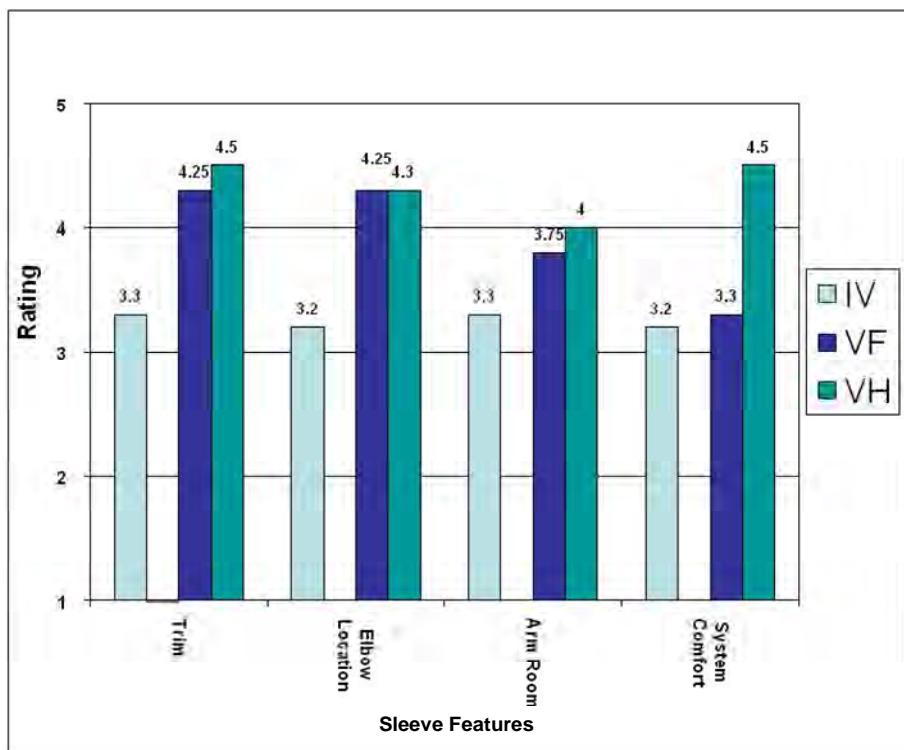


Figure C-2. Participant ratings related to sleeve system features.

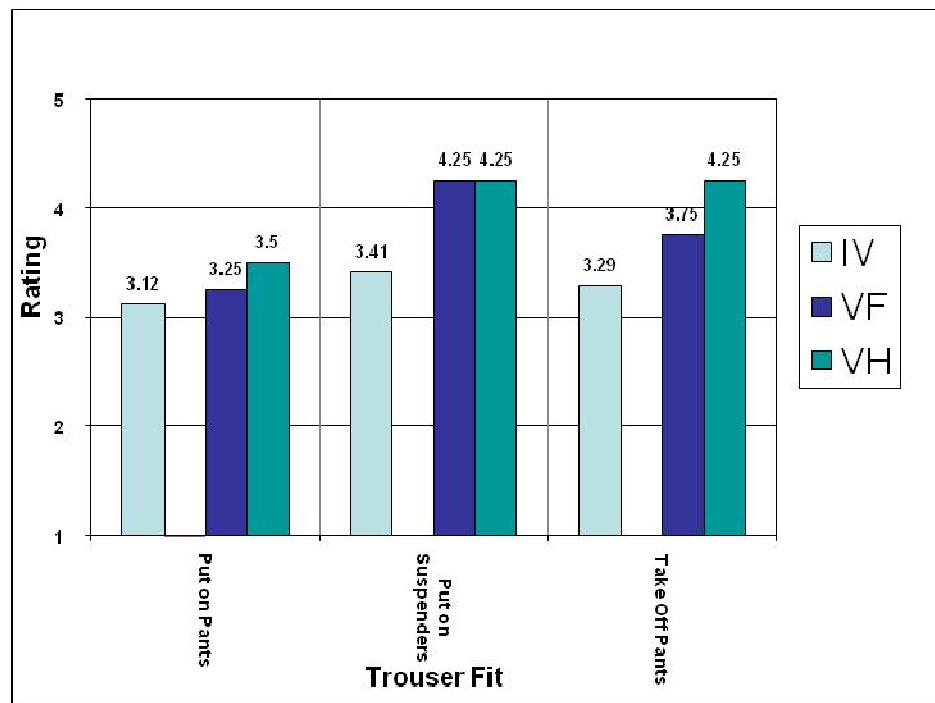


Figure C-3. Participant ratings related to trouser fit.

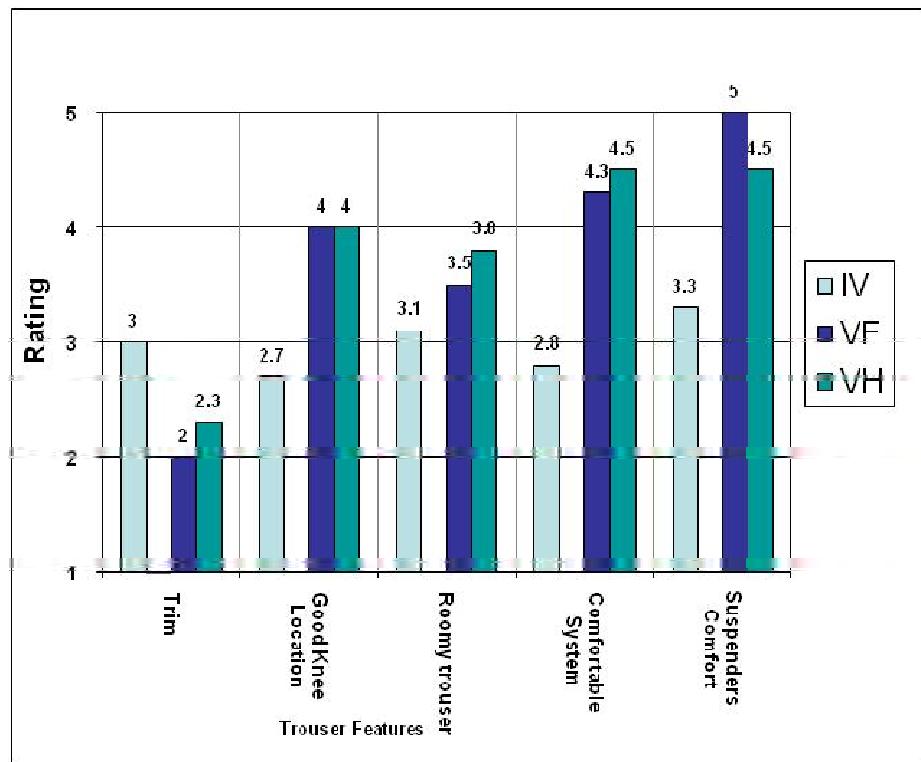


Figure C-4. Participant ratings related to trouser features.



Figure C-5. Participant ratings related to fasteners and closures.

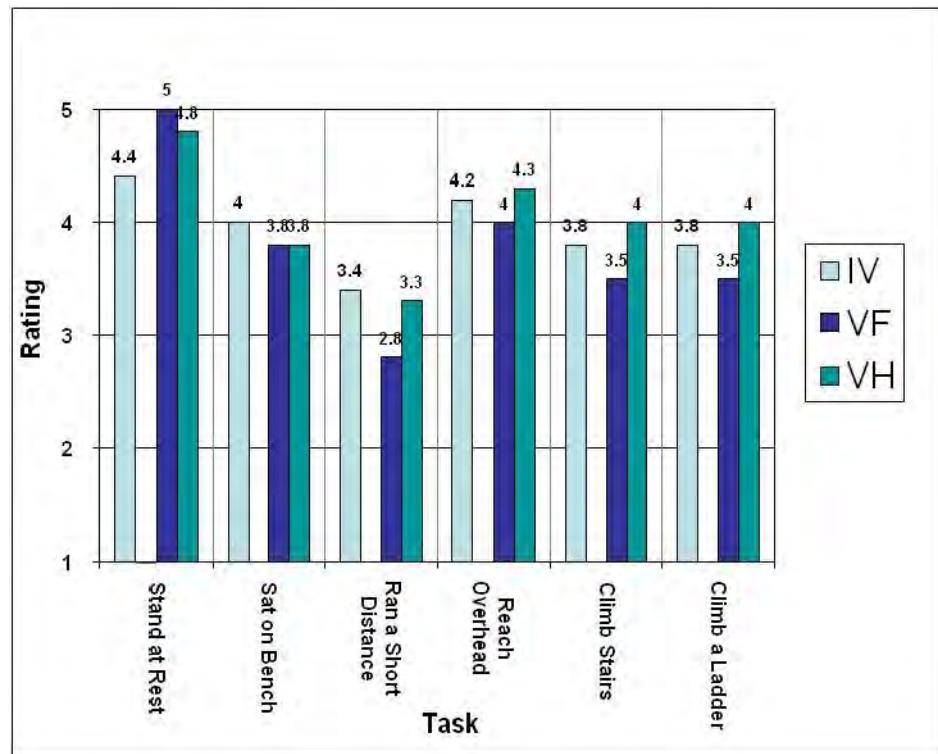


Figure C-6. Participant ratings related to task accomplishment while wearing the system (round 1).

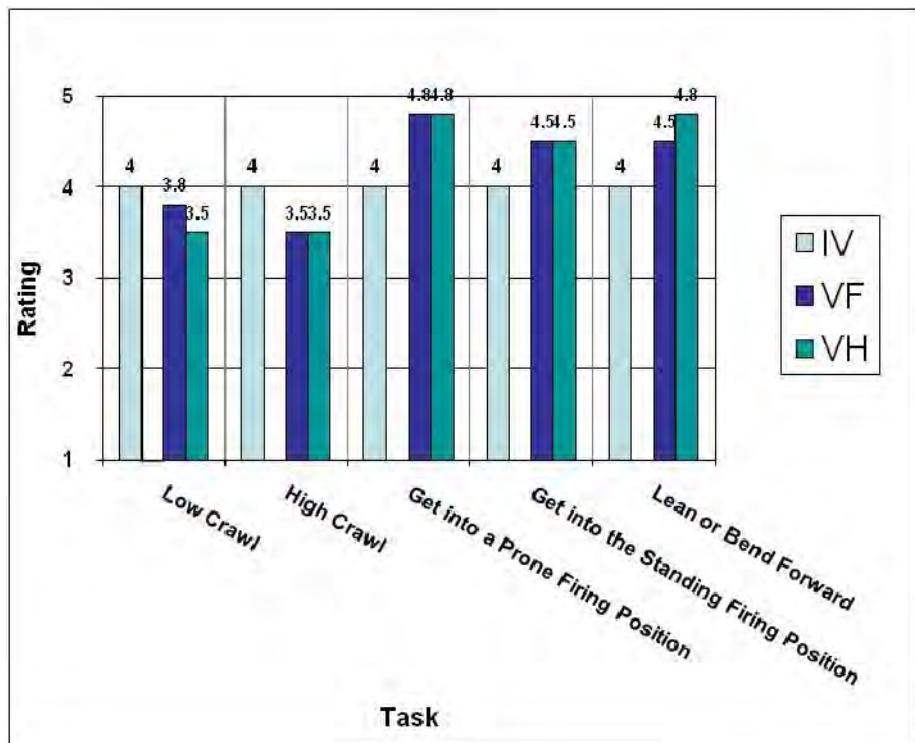


Figure C-7. Participant ratings related to task accomplishment while wearing the system (round 2).

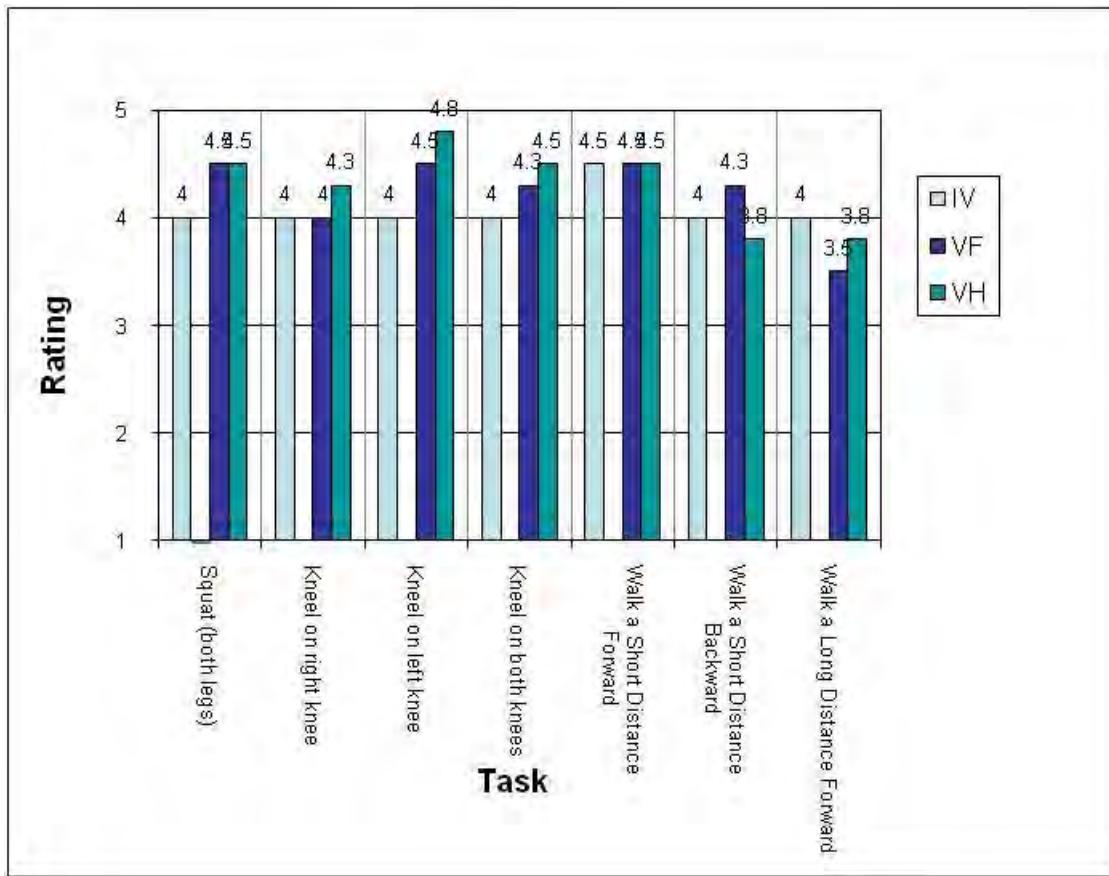


Figure C-8. Participant ratings related to task accomplishment while wearing the system (round 3).

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Appendix D. QuadGard V Photographs

Figures D-1–D-17 show the participants wearing the QuadGard V during the nonobstacle course exercises, mobility/portability obstacle course, and live firing.



Figure D-1. Participant wearing QuadGard V with arms extended horizontally to the sides.

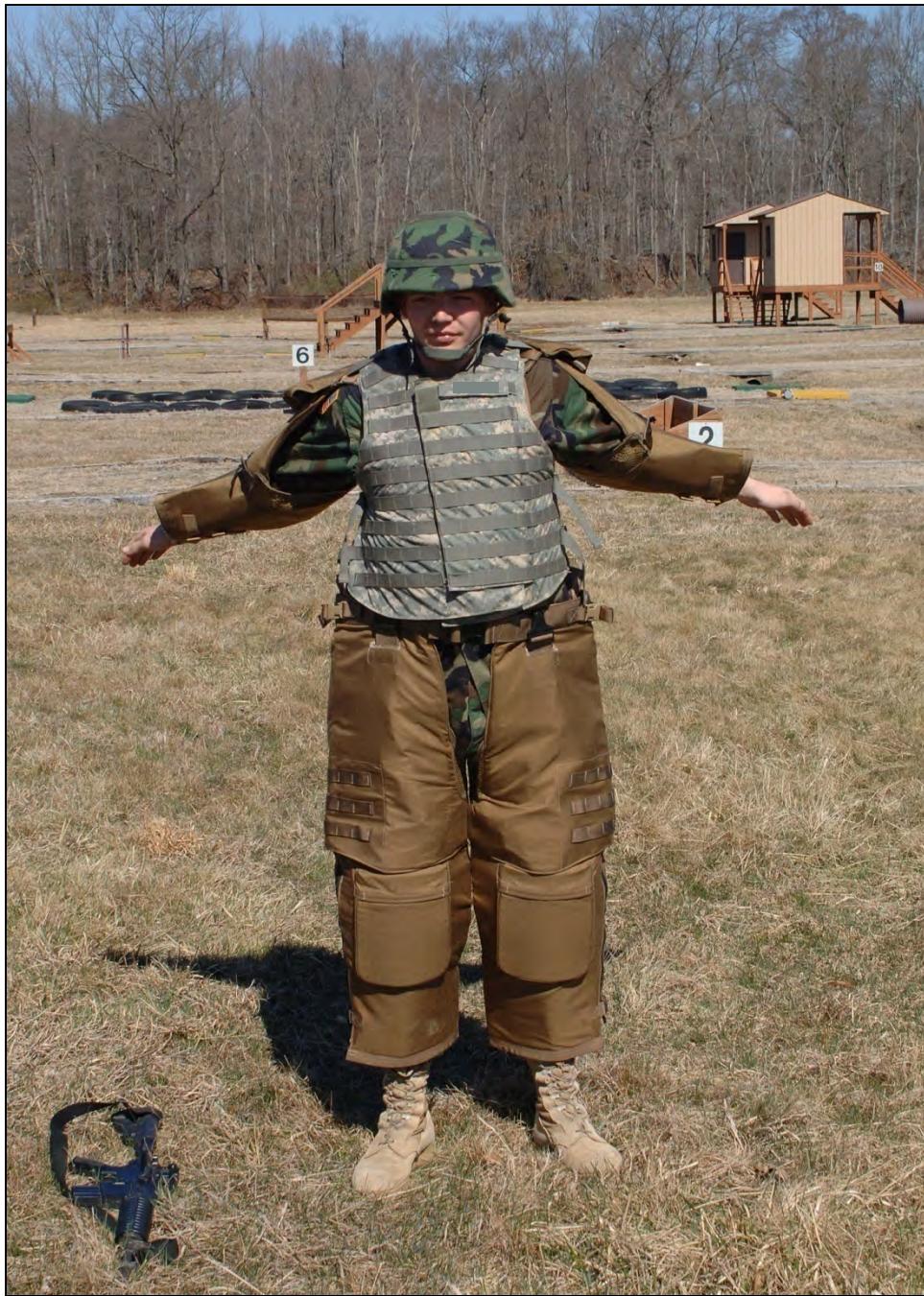


Figure D-2. Participant wearing QuadGard V with arms swung horizontally to the rear.



Figure D-3. Participant wearing QuadGard V with arms raised vertically, then palms touch.



Figure D-4. Participant wearing QuadGard V with feet apart, left knee bent and touching the ground.



Figure D-5. Participant wearing QuadGard V with feet apart, both knees bent in a squat position.



Figure D-6. Participant wearing QuadGard V with feet apart, standing upright, grenade in hand, extending right arm backward then forward to throw an inert grenade.



Figure D-7. Participant wearing QuadGard V assuming the prone firing position. (Using the right hand, grasp an inert grenade and throw the grenade forward at the target.)



Figure D-8. Participant wearing QuadGard V assuming the prone firing position and shouldering the weapon with the right arm.



Figure D-9. Participant wearing QuadGard V climbing a ladder (at least four steps) upward, then downward.



Figure D-10. Participant wearing QuadGard V climbing stairs (at least four steps) upward, then downward.



Figure D-11. Participant wearing QuadGard V low crawling on elbows and knees for a short distance (30 ft).



Figure D-12. Participant wearing QuadGard V climbing the cargo net.



Figure D-13. Participant negotiating an obstacle while wearing QuadGard V.



Figure D-14. Participant negotiating the high fence while wearing QuadGard V.

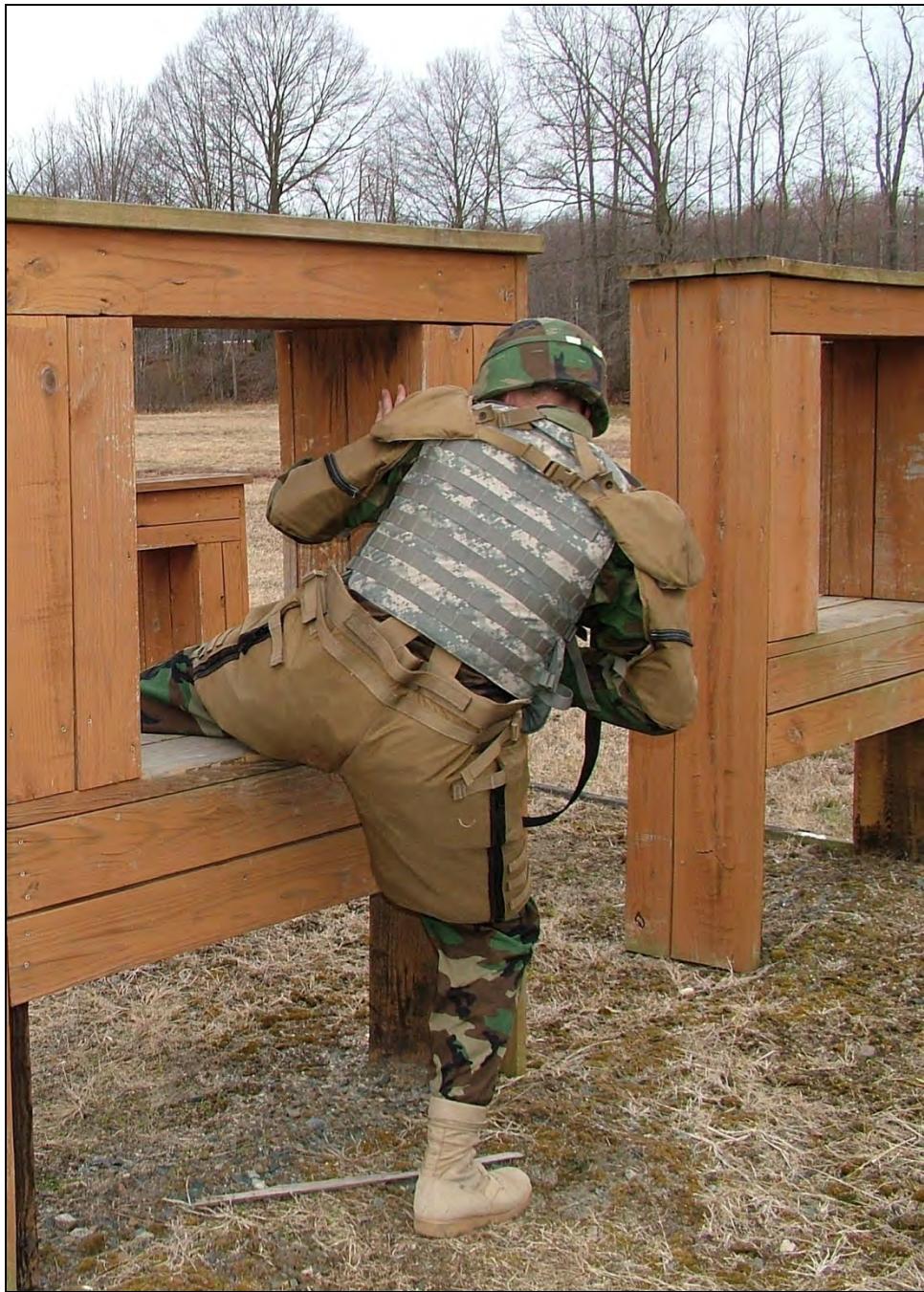


Figure D-15. Participant negotiating the windows while wearing QuadGard V.



Figure D-16. Participant in the prone position, wearing QuadGard V and firing an M4 weapon.



Figure D-17. Participant wearing a QuadGard V and firing an M4 weapon while in a supported standing posture.

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